

The University of Chicago

EFFECT OF CUTTING AND FERTILIZER
APPLICATIONS ON GRASS
DEVELOPMENT

A PART OF THE DISSERTATION SUBMITTED
TO THE GRADUATE FACULTY IN CANDIDACY
FOR THE DEGREE OF DOCTOR OF PHILOSOPHY

DEPARTMENT OF BOTANY

By
CARTER MONROE HARRISON

Private Edition, Distributed by
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Reprinted from
PLANT PHYSIOLOGY
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CARTER M. HARRISON

(WITH THREE FIGURES)

Introduction

The production and maintenance of turf on golf courses must take into consideration the varied uses to which the several parts of such a course are put. The ground cover of the "putting greens," "fairways," and "rough" differs markedly. The turf of the putting greens should be of such a density, height, and quality that a golf ball will roll evenly and smoothly over its surface. These characteristics, furthermore, must be maintained throughout the entire playing season even though the blades may be clipped daily to approximately three eighths or even three sixteenths of an inch in length. The fairway turf should consist of grasses whose blades stand firmly and stiffly upright so that they will hold a golf ball up on their ends, "teeing" it up for the next shot. The fairway is usually bordered by the rough. As the name implies, the grasses which compose it are permitted to grow longer; often those of a bushy or tufted nature are included.

Much difference of opinion prevails as to the best treatment of turf to secure a desired result. Factors in the environment coupled with the treatment to which the plants are subjected not only determine the kind or kinds of plants that can be grown, but also influences the growth produced by them during any given season.

Precise methods for the production and maintenance of desirable turf on the fairways of the modern golf course have not been developed. Short cutting of the grass on the fairways during the playing season is generally practiced. At times, it is cut to approximately one half inch. The closer the grass is clipped, the longer will be the intervals between the time of cutting and the time when the grass is long enough to prove troublesome to the game. Lengthening the intervals between cuttings results in a material saving in operative costs. In most instances some practice of fertilizing in addition to the cutting of the grass is necessary. These practices may in extreme instances be quite as harmful as beneficial to the growth of the grass. In fact it is easily possible to weaken or even kill grass by certain treatments, so that the ground is either left devoid of plant life or becomes covered with undesirable plants.

¹ Contribution from the Hull Botanical Laboratory, the University of Chicago, under a fellowship granted by the United States Golf Association Greens Section.

Much difficulty is encountered from the prevalence of low growing weeds, clover, and coarse summer grasses under close cutting treatments given the fairways, whereas the rough which is generally left uncut for longer periods of time or cut higher, is relatively free from such troubles. Also the rough usually stays green and thick after the fairways have become dry and sparse.

It would seem probable, therefore, that if the fairways could be cut in such a manner that a greater amount of leaf surface could be left than is true with the usual close cutting treatment, they too would remain in better condition. This result might be accomplished either by cutting the fairways close and less frequently, or by cutting frequently with the mower raised. The first method might prove troublesome because of the length which the grass would attain during intervals between cuttings, whereas the second would be feasible since it would provide a suitable playing surface and yet prevent serious injury to the grass because of too close clipping.

Some of the obvious detailed problems connected with the maintenance of grass turf are, (1) What response, relative to the quantity and quality of new growth, will grass plants exhibit after being cut at different heights? (2) Do the different species and varieties of grass respond similarly to any given treatment with respect to both the top and root growth produced? (3) What effect will cutting have upon the amount and length of root systems produced? (4) How do the treatments affect the ability of the plants to extend themselves vegetatively? (5) What are the effects of various fertilizer treatments on the amount of top growth produced by the plant in relation to the amount of such growth removed or allowed to remain?

In this investigation, solutions to certain of these problems were sought. The particular studies and experiments undertaken had to do with (a) the effect of frequent cutting to three different heights, one-half inch, one and one-half inches, and three inches upon the development and the dry weight of the roots produced; (b) the effect of cutting combined with fertilizing upon the length of roots produced; (c) the external structural responses of the grass to cutting and fertilizing as they relate to the quantity and quality of the turf; and (d) any anatomical variations which might be brought about by cutting, or fertilizing, or a combination of both.

Although considerable work has been done on agronomic herbaceous plants with respect to frequency and time of cutting, and with respect to the effect of fertilizer applications on the yield and permanence of stand, there are virtually no detailed records of experiments dealing with fairway maintenance.

As early as 1879 LAWES and GILBERT (15) found that various fertilizers greatly affected the relative numbers of different species of herbaceous plants present in a permanent meadow. Nitrogenous fertilizers, in general, favored the growth of grasses and reduced all other plants to a minimum, while the absence of nitrogenous fertilizers enhanced the growth of leguminous and other miscellaneous species. They also found that when nitrogen alone was used, the yield was increased considerably the first ten years of the experiment but dropped almost to the level of the checks the second ten years. KOSINSKI (12) and GODLEWSKI (6) showed that the addition of nitrogen salts to plants restricted the growth of roots in length and favored the growth of the stems. GODLEWSKI further showed that presence of sugar in a nitrogen free solution favored the growth of roots. HARRIS (11) found that wheat grown to maturity without fertilizer had a greater proportion of roots to tops, but where a nitrogenous fertilizer was added top growth was greater in proportion to the roots though the total root growth was greater in the latter case. GREEN (9) noted that in general frequent cuttings induced quick growth. KRAUS (13), ALBERT (1), and MCKEE (16) found that clipping of the tops of herbaceous plants retarded root development. SALMON *et al.* (23) found that cutting alfalfa at immature stages thinned the stand and lowered the yield. GREGORY (10) and CRIST and STOUT (3) stated that there appears to be a reciprocal effect between tops and roots of plants. WATERS (29), NELSON (17), and ALDOUS (2) showed that cutting frequently or cutting at immaturity depleted the reserves in the roots of herbaceous plants. NELSON also found a slow recovery after cutting, lower yields, and increased weed infestation, besides an increase on the plants of crown buds, shoots, and main stems, as a result of early and frequent cutting.

GRABER *et al.* (7), STURKIE (28), and PIERRE and BERTRAM (19) showed that the underground parts of alfalfa, Johnson grass, and kudzu could be reduced in weight below what they were at the beginning of the experiment by frequent and close clippings, and that the amount of reduction was associated with the severity of the cutting. PIERRE and BERTRAM found with kudzu that the roots of plants cut six times per season decreased in weight during a period of two years, those from plants receiving four cuttings increased about 150 per cent., those receiving two cuttings, about 400 per cent., and those receiving one cutting, about 1250 per cent. The percentage of reserve starch and nitrogen was found to be less than one-half as much in the roots of plants receiving six cuttings as in those of plants receiving four or fewer cuttings. The percentage of total sugars, however, was found to be greater. This was taken as an indication that a change from starch to sugar was taking place in the roots of plants receiving six cuttings, in order to produce new top growth. FITTS (4), working

with the fine turf grasses, found that the length of roots increased in relative proportion to the height to which the tops had grown. When the grass was surface fertilized, in order to produce a good turf, the roots were short, but when the grass was starved, the roots were longer and the turf was poorer. FAGAN, MILTON and PROVAN (5), in treating a mixture of grasses, grown from seed, with nitrate of soda, noted in the first harvest year that the response to the fertilizer was greater in the case of the grasses than of the clovers. This, coupled with the late growth of the clover, resulted in the latter, under most conditions of the investigation, being shaded and smothered by the grass. When the grass was cut at weekly intervals, the weight of clover in the total growth produced was equal to the weight of Italian rye grass (the most prominent grass). The yield of dry matter from the same area was much greater under a monthly system of cutting than under a weekly one. STAPLEDON and BEDDOWS (25), using orchard grass, concluded that repeated cuttings during the current season produced considerably less than the amount of a hay and aftermath crop. Repeated cutting reduced the root systems of the plants and retarded the growth produced early in the following spring. The pasture propagants gave as much as a 30 per cent. decrease in the amount of roots produced when compared with the hay plants and in some cases the difference amounted to 100 per cent. There was a wide response range to continued cutting in the pedigreed strains. Some resisted the treatment in a manner quite superior to that of others and showed only a slight reduction in roots. The plants with the highest yield did not necessarily have the heaviest root systems, but the nine highest yielding had roots somewhat heavier than the nine lowest yielding. Super-phosphate was without material quantitative or qualitative effects on root development, or on the stem to leaf ratio in the hay, aftermath, or pasture. Neither super-phosphate nor sodium nitrate alone was able to counteract the depressing influence of continued cutting.

REAM (20), STAPLEDON (24), STAPLEDON and MILTON (27) and STAPLEDON and DAVIES (26) found that root, tiller, or rhizome development and yield of the grasses studied were associated with the cutting treatment. The more drastic the cutting treatment, as measured by amount and frequency of defoliation, the less was the yield of roots, rhizomes and tops. The addition of nitrogenous fertilizers augmented the amount of yield of plant parts with a few exceptions where the cuttings were very short and frequent.

During the last fifteen or more years, several investigators have shown that chemical studies were pertinent to growth relations. KRAUS and KRAYBILL (14), NIGHTINGALE (18), and REID (21) have pointed out some apparent relationships between growth responses of plants and plant parts,

and the carbohydrate reserves and nitrogenous compounds within them. WELTON *et al.* (30) showed that the mowing of Canada thistles delayed organic food storage, resulting in a killing of the weaker plants. The more frequently the thistles were mowed, the more effective was the eradication. REID (22) showed that the relative amounts of carbohydrate to nitrogen compounds stored in seeds affected the ratio of tops to roots in the seedlings and that added nitrogen did little to augment growth unless light conditions were favorable for carbohydrate synthesis. GRABER (8) stated that frequent and close removals of the top growth of grasses having abundant reserves made for a heavy draft on the supplies of available nitrogen, so that the first limiting factor in growth might be nitrogen deficiency, but when regeneration was constantly stimulated by abundant mineral fertilizers, especially nitrogenous ones, the carbohydrate reserves were rapidly used with slight opportunity for replenishment and, as a result, they often became the principal factors limiting growth.

Experimental data

EXPERIMENT I

MATERIALS AND METHODS.—Preliminary greenhouse tests were made on three grasses in the spring of 1929. Three common golf course grasses were selected for the work, namely, Kentucky bluegrass (*Poa pratensis*), red fescue (*Festuca rubra*), and Colonial bent (*Agrostis capillaris*). The flats in which the grasses were grown were twenty-two inches long, fifteen inches wide, and two and one-half inches deep. They were filled with a good grade of black top soil. The seed was sown at the following rates: Kentucky bluegrass, 1.91 grams per flat; Colonial bent, 1.43 grams per flat; and the red fescue, 2.86 grams. These rates correspond to 2.0 pounds, 1.5 pounds, and 3.0 pounds per thousand square feet respectively.

The seed was sown on March 13th, the experiment was set up in triplicate, and the cutting treatment was started April 15th. The grass was cut to three heights, one-fourth inch, one and one-half inches, and three inches. In addition three flats of each grass were clipped short and ammonium sulphate was added on April 30th and May 22nd. The first application was made at the rate of two pounds per thousand square feet and the second at the rate of seven pounds per thousand square feet. The grass in all of the flats was cut sixteen times between April 15th and July 5th.

Beginning July 5th, the grass roots were washed from the soil with as much care as possible. The roots were distinctly matted in the grass cut to the higher levels, but this was not true of the most closely clipped flats.

RESULTS.—The results are recorded in table I in grams per square foot of surface area.

TABLE I
WEIGHT OF ROOTS IN GRAMS PER SQUARE FOOT OF SURFACE AREA

VARIETY	RED FESCUE		BLUEGRASS		COLONIAL BENT	
TREATMENT	GREEN WEIGHT	DRY WEIGHT	GREEN WEIGHT	DRY WEIGHT	GREEN WEIGHT	DRY WEIGHT
	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>	<i>gm.</i>
Short cut, $\frac{1}{4}$ inch	6.8	1.4	8.5	1.6	13.8	2.1
Short cut, $\frac{1}{4}$ inch and ammonium sulphate	4.3	1.0	6.8	1.3	Killed	
Medium cut, 1.5 inches	51.6	8.6	36.3	7.5	29.4	5.0
Long cut, 3 inches	78.0	13.7	61.0	11.7	59.1	7.7

Table I indicates that there is a considerable difference in the amount of roots produced as a result of the different cutting treatments and also by the different grasses. The root systems of the bent grass which was cut short weighed nearly double that of either of the other two grasses receiving the same treatment. The percentage increase in roots between plants when cut at three different heights is large and indicates a direct correlation between the amount of top growth and the amount of root growth produced.

The character of the response of the short clipped bent grass that was fertilized to the combination of a heavy nitrogenous fertilizer and shading of the greenhouse was interesting. The grass had been growing in a greenhouse that was not shaded. Until the greenhouse was covered to cut down the light, these flats were a beautiful green, while the flats having no nitrogen, and clipped short, were yellowish in color. No later than three days after the shade mixture had been applied to the greenhouse roof, the heavily fertilized grass rapidly took on a scalded appearance until only the plants near the sides of the flat showed a healthy green color. In the meantime, the grass that was clipped short and that had received no nitrogen turned from a yellowish color to a dark green. The plants which appeared scalded died and after examination of the material their death could not be attributed to fungus troubles. Appearing as it did about a week after a heavy fertilization with nitrogen and a decrease in the light intensity, it was thought that possibly in the absence of sufficient manufactured carbohydrates, the nitrogen was toxic and brought about the scalded condition.

EXPERIMENT II

GREENHOUSE EXPERIMENT WITH KENTUCKY BLUEGRASS AND RED FESCUE.—Because the flats used in the first experiment were too shallow to allow the

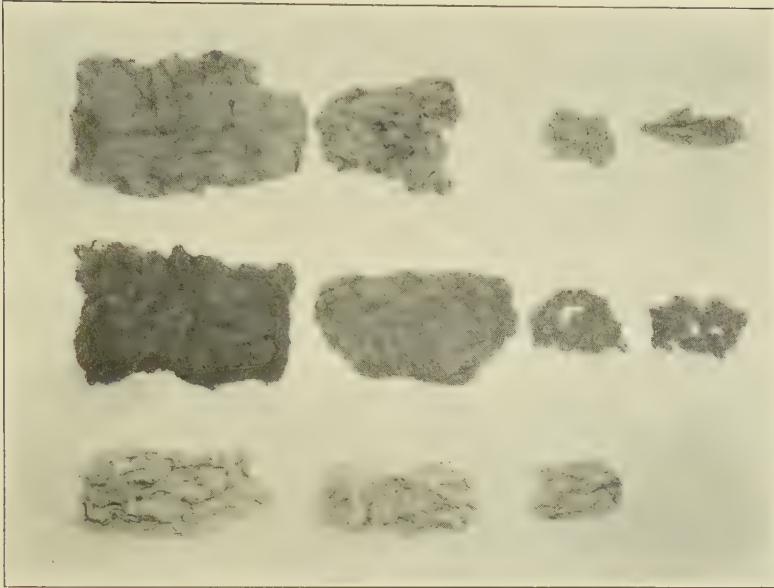


FIG. 1. Photograph showing bulk of roots produced by different grasses when cut to three heights and when nitrogen is added to short cut grass.

Upper row: Kentucky bluegrass. Reading left to right: cut long, cut medium, cut short, and cut short plus nitrogen.

Middle row: Red fescue. Treated same as bluegrass.

Lower row: Colonial bent. Treated same as bluegrass. Roots from the grass plants that were fertilized and clipped short are missing because the grass killed.

roots of the plants to grow downward and because they dried out too rapidly, another experiment was begun in the fall of 1929 to duplicate in part and supplement in some features the preliminary study.

MATERIALS AND METHODS.—Wooden boxes of approximately one cubic foot volume were obtained. These were filled with a mixture of eight parts of black soil, two parts of quartz sand, and one part of leaf mold. The soil was sifted to remove large particles of organic material and gravel. The seed was sown on September 25th.

Fertilizer applications were made once per month during January, February, and March. The applications consisted of the following:

1. Nitrogen, 1.12 grams of ammonium sulphate.
2. Nitrogen-phosphorus, 1.12 grams of ammonium phosphate.
3. Nitrogen-potassium, 0.85 grams of potassium nitrate plus 0.57 grams of ammonium sulphate.
4. Nitrogen-phosphorus-potassium, 1.12 grams of ammonium sulphate plus 1.15 grams of monobasic potassium phosphate. The amount of nitro-

TABLE II
 DRY WEIGHT OF ROOTS IN GRAMS PER SQUARE FOOT FOR THE DIFFERENT CUTTINGS AND FERTILIZER TREATMENTS IN KENTUCKY BLUEGRASS
 AND RED FESCUE

BLUEGRASS										FESCUE									
		CUT ½ INCH	± MEAN	CUT 1½ INCH	± MEAN	CUT 3 INCH	± MEAN	CUT ½ INCH	± MEAN	CUT 1½ INCH	± MEAN	CUT 3 INCH	± MEAN						
Check	1	2.6	-0.03	7.8	-0.07	10.7	-1.47	4.7	-0.23	7.5	-0.90	13.8	-0.63						
	2	3.0	+0.37	8.3	+0.43	11.5	-0.67	4.5	-0.43	9.1	+0.70	16.1	+1.67						
	3	2.3	-0.33	7.5	-0.37	14.3	+2.13	5.6	+0.67	8.6	+0.20	13.4	-1.03						
Nitrogen alone Ammonium sulphate	1	4.3	+0.47	6.8	-0.60	10.0	+0.57	7.0	+0.93	9.2	+0.43	11.0	-0.03						
	2	3.3	-0.53	7.4	± 0.0	9.5	+0.07	5.2	-0.87	8.9	+0.13	10.6	-0.43						
	3	3.9	+0.07	8.0	+0.60	8.8	-0.63	6.0	-0.07	8.2	-0.57	11.5	+0.47						
Nitrogen and phos- phorus Ammonium phosphate	1	3.2	+0.23	6.5	-0.50	8.9	-0.63	5.2	+0.23	8.5	+1.0	10.3	+0.60						
	2	2.4	-0.57	7.1	+0.10	10.6	+1.07	4.8	-0.17	6.8	-0.70	9.5	-0.20						
	3	3.3	+0.33	7.4	+0.40	9.1	-0.43	4.9	-0.07	7.2	-0.30	9.3	-0.40						
Nitrogen and potas- sium Potassium nitrate and ammonium sulphate	1	4.0	+0.30	8.1	+0.17	8.5	+0.50	5.6	+0.20	7.0	+0.03	9.8	+0.03						
	2	3.9	+0.20	8.6	+0.67	8.3	+0.30	5.4	± 0.0	8.1	+1.07	10.5	+0.73						
	3	3.2	-0.50	7.1	-0.83	7.2	-0.80	5.2	-0.20	6.0	-1.03	9.0	-0.77						
Nitrogen phosphorus and potassium Potassium acid phosphate and am- monium sulphate	1	3.1	+0.67	7.8	-0.03	10.0	+0.70	5.6	+0.07	7.1	+0.23	11.5	+0.43						
	2	2.2	-0.23	8.4	+0.57	9.2	-0.10	5.9	+0.37	6.3	-0.57	10.5	-0.57						
	3	2.0 ¹	-0.43	7.3 ¹	-0.53	8.7 ¹	-0.60	5.1 ¹	-0.43	7.2 ¹	+0.33	11.2 ¹	+0.13						

¹ Weight of roots of the flats from which the photographs were obtained.

gen added to the grass in each flat was the same regardless of the salt used. The experiment was set up in triplicate.

Beginning November 7th the plants were cut and the cutting continued each week thereafter until the close of the experiment. Fifteen flats of each species of grass were cut to one-half inch, fifteen to one and one-half inches, and fifteen to three inches. All clippings were removed from the flats. Beginning April 21st the soil was washed from the roots. The dry weight of the roots was recorded, the results being given in table II.

From table II it is obvious that the cutting heights made considerable difference in the amount of roots produced and that very little can be said in favor of the fertilizer treatments with respect to root growth. More difference is apparent between the triplicates of a certain treatment than between treatments.

Besides weighing the roots produced by the different treatments, it was thought advisable to select a flat of grass of each of the three cutting heights where the best top growth was obtained from which to get photographs of the height of cut, the density of the turf, and the length and amount of roots produced. The complete fertilizer gave what appeared to be the best top growth at all three heights. The fescue was selected likewise. The rhizomes were carefully picked out of the three fertilized bluegrass flats, and likewise out of three check flats, and the oven dry weight was recorded as in table III.

TABLE III

TREATMENTS	TOTAL DRY WEIGHT OF RHIZOMES PER FLAT
Bluegrass—clipped long, potassium phosphate and ammonium sulphate	<i>gm.</i> 0.726
Bluegrass—clipped long, check	0.594
Bluegrass—clipped medium, potassium phosphate and ammonium sulphate ..	0.400
Bluegrass—clipped medium, check	0.225
Bluegrass—clipped short, potassium phosphate and ammonium sulphate ...	0.018
Bluegrass—clipped short, check	0.008

Many more rhizomes were produced by the grass cut high than by that cut to a medium height, and decidedly more were produced by the grass cut to a medium height than by that cut short. In fact, very few of the plants in the short cut flats had visible rhizomes.

Sections were cut of representative plants selected from the checks and from those receiving nitrogen, in the three cutting heights. This was done on both the fescue and the bluegrass. Nothing could be noted from the

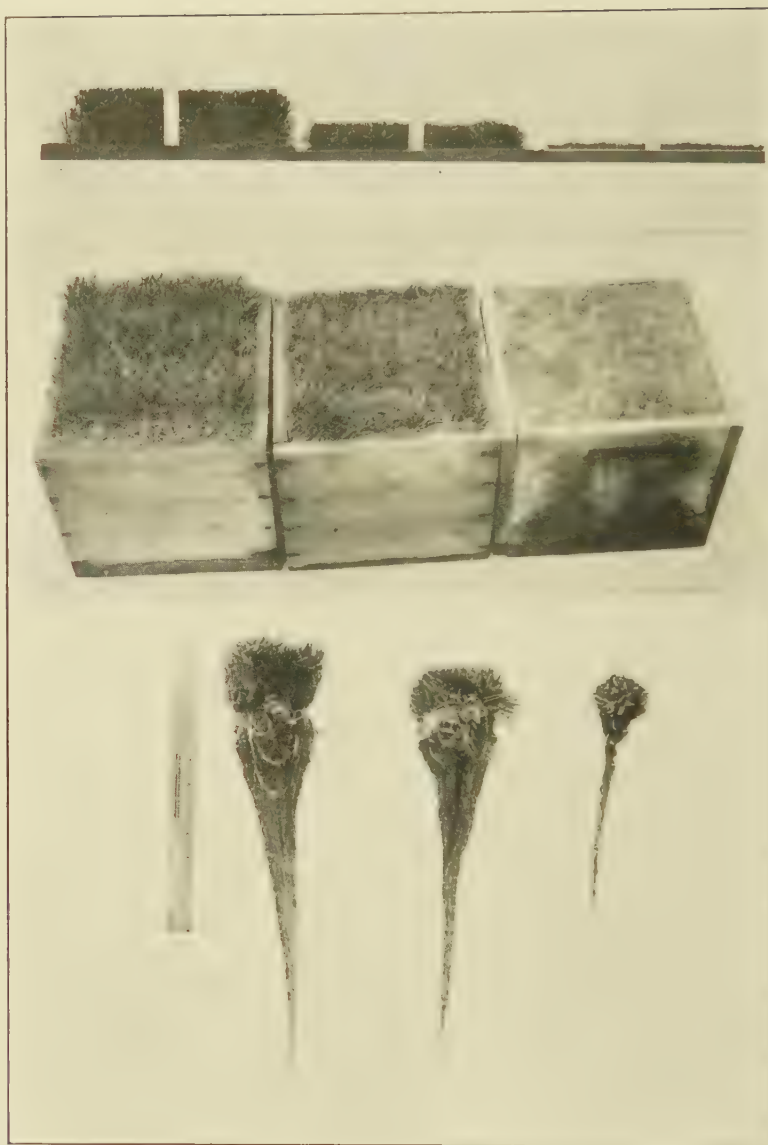


FIG. 2. Three bluegrass flats to which a complete fertilizer had been added, showing: above, the height of cut; middle, the turf produced at those heights; and below, the mass and length of roots produced.

slides that was not apparent in the external structure of the plants. It was observed that the shorter cutting of the fescue induced much more tillering than was the case in those cut longer. The grass cut to a medium

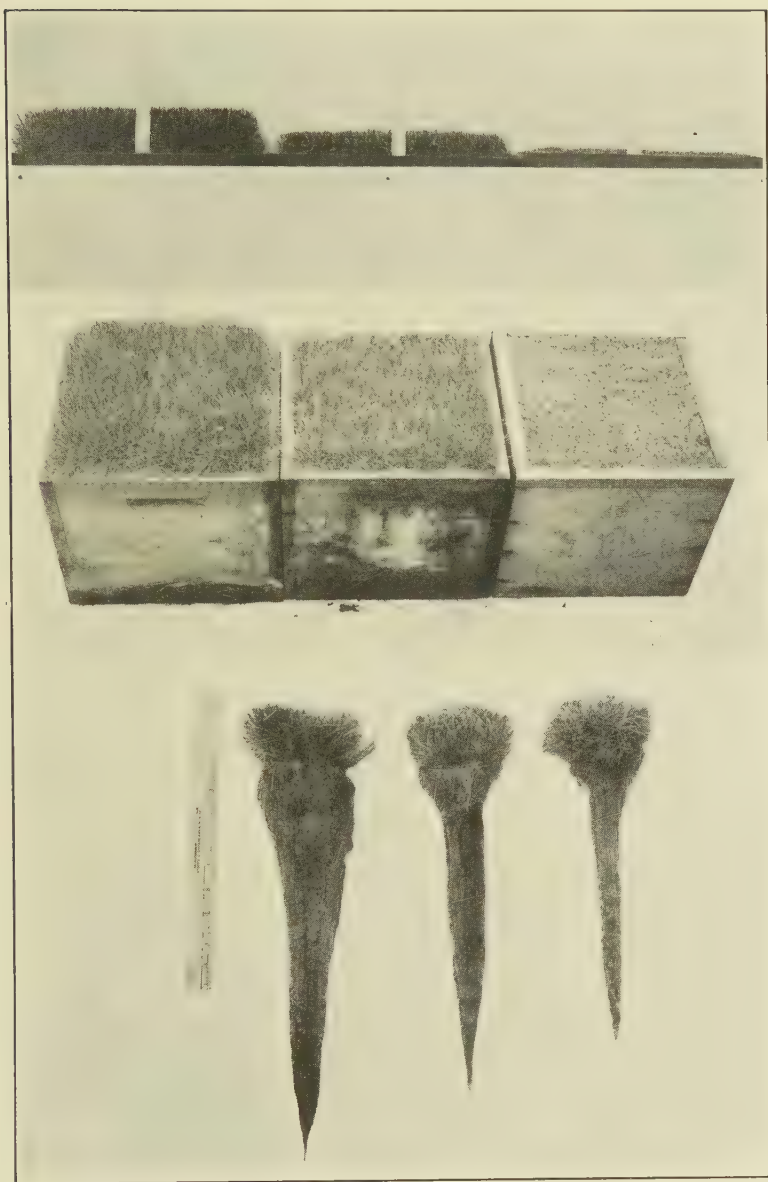


FIG. 3. Three fescue flats to which a complete fertilizer had been added, showing: above, the height of cut; middle, the turf produced at those heights; and below, the mass and length of roots produced.

height had stiffer and more upright leaf blades than that cut long, the long cut plants having a tendency to lop over. This was probably due to length

of blade rather than to a difference in the anatomical structures of the two. The plants clipped short tillered more than those cut to a medium height, but the leaf blades were not nearly so stiff. The grass cut to a medium height would hold up a golf ball, while neither of the others would do so. None of the cutting treatments appeared to result in a thinning of the fescue turf. The grass in the check flats could be picked out late in February after a period of bright weather, and there was also a difference in length of top growth in favor of the fertilized grass. The bluegrass, on the other hand, killed considerably when clipped short, that with the medium cutting height produced a good turf with stiff leaf blades, and that cut long produced a turf that lopped over as did the fescue which was clipped high. The effect of the nitrogen on the bluegrass was not apparent until late in February after the second fertilizer application. All the grass had been a dark green color until this time when the weather became bright and clear as contrasted with the cloudy, sunless period preceding it. During these sunny days, the checks in all three cutting heights turned a greenish yellow while the grass in the flats receiving nitrogen remained a dark green. Between cutting periods, the grass clipped long receiving nitrogen grew approximately three inches, while that in the checks grew one inch. The medium cut grass showed the same response but to a less degree, the growth in height being about two inches in the fertilized flats of grass as compared to three quarters of an inch in the checks. In the flats of grass cut short and fertilized, the plants sent up one spindly blade, the turf thinned out badly, and it appeared as if the nitrogen was harmful here because the grass in the check flats did not thin out or have this spindling habit of growth.

It was noted that the shorter the clipping treatment the smaller the subsequent plant parts became. The roots were finer and shorter and the leaf blades were narrower and shorter. The growth in height corresponded to the size of the plant. The plants in the check flats, regardless of the cutting height, appeared to be storing carbohydrates as evidenced by a yellowish green color of their leaves when compared with the darker green color of the leaves of the plants receiving nitrogen. This might possibly indicate that as the severity of the cutting treatment increased, the new roots produced by the plant became fewer, shorter and finer. Thus a gradual adjustment between the amount of top growth and root growth took place, the final result being that in no case was the root system sufficiently extensive to gather enough nitrogen to prevent carbohydrate storage.

Summing up the general observations, it appears as if the nitrogen had resulted in increased top growth in all cases except the short clipped bluegrass. The fescue which was cut short tillered more than that cut long. That cut at a medium height, however, had the most desirable leaf blades from a golf course view-point.

The foregoing data show that the shorter the grass was clipped, the fewer roots were produced. It has been shown by several workers that frequent removal of top growth influenced the subsequent yield of tops, lessened the carbohydrate storage, and if the clipping were severe enough, no carbohydrates were stored. It has also been noted that when the tops are severely clipped, the weight of the root systems may be reduced below the initial weight at the start of such treatment. Lessening the leaf area resulted in the production of fewer, smaller roots than was the case when the treatment was not so severe. The size of the successive leaves produced by the plant depended on the cutting treatment: the more severe the treatment, the smaller they became. As the clipping treatment became more and more severe, generally less and less leaf area was left to manufacture carbohydrates, which are necessary both for the growth of roots and for subsequent top growth.

Removal of photosynthetic surface can be carried to such an extreme that the grass plant is weakened to such a degree that it can no longer survive either drouth, disease, extremes of heat or cold, or the competition of plants which have growth characteristics enabling them to escape the close clipping by tillering, or by growing almost flat on the surface of the ground. These plants, such as white clover, dandelion, crab grass, knot-weed, and plantain, retain sufficient leaf area to maintain themselves under clipping practices which are very detrimental to the growth of upright growing grasses such as Kentucky bluegrass. Bluegrass continues to grow erect, and the new chlorophyll bearing tissue is continually cut off as it is produced. Field observations as well as greenhouse studies show that Kentucky bluegrass cannot maintain itself under ordinary field conditions if it is cut shorter than three-quarters of an inch more frequently than once each week. The plants extend themselves very little vegetatively when these practices are followed. The rhizomes formed are few in number and grow very slowly. If the grass is allowed to grow longer or is cut less frequently, there is sufficient production of rhizomes to insure good perennial turf, and besides, the undesirable plants are kept hidden or are crowded out by the vigorous growth of the grass. Even among the different grasses, there are species that can maintain themselves where others are killed by the short and frequent clipping. Most of the vegetative and seeded bent grasses that are in use today for turf purposes produce considerable chlorophyll-bearing tissue near the surface of the ground in such a manner as to escape close clipping. It is this characteristic that makes them valuable for the putting greens. Red fescue tillers when cut short, and produces many leaves close to the ground away from the mower blades. Therefore it is able to withstand more severe cutting than grasses which do not have this habit of growth.

The relationship that exists between carbohydrates and nitrogen in plant nutrition has been pointed out by workers in the field, and it has been shown that an application of nitrogen is of little use in subsequent growth unless the plant has an available supply of carbohydrates or is capable of manufacturing it. An excess of mineral fertilizer cannot take the place of carbohydrates in plant growth. The appended data show in general that root growth will not respond to fertilizer applications if the ability of the plant to manufacture carbohydrates is impaired by short clipping. The mowers should be raised on the fairways where the cutting treatment is proving dangerous, and cutting should be discontinued in the fall as early as possible in order that the plants may store foods for use during the season of short and frequent clipping.

Summary

1. Clipping at different heights affected the amount of roots produced on the grasses studied. The shorter the grass was cut and the more the leaf area was reduced, the smaller was the quantity of roots produced.
2. Grasses having different growth characteristics responded differently to the cutting treatments. The fescue tillered more when cut short than when cut long, and the bluegrass produced fewer rhizomes when cut short than when cut long.
3. Mineral fertilizers did not compensate for a lack of top growth in the production of roots.
4. The killing of the grass was not due to a cutting off of the buds, but to a gradual carbohydrate starvation to a point beyond which the plants could not maintain themselves.
5. The addition of nitrogen brought about an increase in top growth, but the weight of roots was not increased over that of the roots of the unfertilized grass.

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